Contact measurement of turbulent intensity of the pipe flow using UVP

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In this study, the authors directly inserted the transducer of the UVP with an accurate movable device into the flow parallel to the flow axis. We investigate the measurement accuracy of the velocity and the possibility of the velocity fluctuation measurement concerning with turbulent intensity using this method. This method is free from the effects of reflection and refraction at the pipe wall unlike the UVP measurement through the pipe wall, although this method has the demerit of contact with liquid. In addition, we adopted micro bubbles as the reflector of the ultra sound. They are environment-friendly compared with fine solid particles which may pollute the environment, and they are economy. These bubbles are generated by the pressurized dissolution method. As the results of the measurement, the time-averaged velocity profiles measured by the UVP contact measurement agreed well with the calculated results by the (1/n) power's law. The deviations are smaller than those measured by the UVP measurement through the pipe wall. RMS values of velocity fluctuation divided by the cross-sectional averaged flow velocity U are presented by the UVP contact measurement. The results agreed with the tendencies of Hosokawa et al.'s and Laufer's data.

Keywords: Pipe flow, Velocity profile, Ultrasonic Velocity Profile monitor, Micro bubble

1 INTRODUCTION

Piping is used in various industrial fields and the flowing characteristics have been researched by a lot of researchers. However, in the case the opaque piping and/or the opaque fluid, it is difficult to measure the flow using light such as the laser beam or the PIV. The ultrasonic velocity profile monitor (UVP) can be applied to such a case.

The measurement of the flow in pipes using the UVP is usually carried out through the pipe wall. However, because the ultrasonic wave is reflected and refracted complexly through the pipe wall with the curved surface, it may be difficult to obtain the high signal to noise ratio data in a round pipe. In addition, only the transducer direction component of the velocity can be measured because of setting up the transducer at a certain acute angle to the radial axis.

Then, in this study, the authors directly inserted the transducer of the UVP with an accurate movable device (it moves from the pipe wall to the center) into the flow parallel to the flow axis. We investigate the measurement accuracy of the velocity and the possibility of the velocity fluctuation measurement concerning with turbulent intensity using this method.

This method (UVP contact measurement) is able to be used for the opaque piping and/or opaque liquids unlike the LDV, not necessary to calibrate before the experiment unlike a heat-wire airflow meter, and free from the effects of reflection and refraction at the pipe wall unlike the UVP measurement through the pipe wall, although this method has the demerit of contact with liquid. In the near future, the authors plan to make a precise measurement of the flow around a large bubble using this method.

In addition, we adopted micro bubbles as the reflector of the ultra sound. As for the first reason, they are environment-friendly compared with fine solid particles which may pollute the environment. Secondly, they are economy. Once we have a micro bubble generator, we don't have to pay any more than the electricity expense. These bubbles are generated by the pressurized dissolution method.

In order to verify the validity of this method, we measured the velocity distribution and computed the root-mean-square value of the velocity fluctuation in turbulent flow of the water single phase in a vertical pipe of 53.5mm I.D.

2 EXPERIMENT

2.1 Experimental apparatus and experimental method

Figures 1 and 2 show the experimental apparatus and transducer installed at the exit part of the pipe, respectively. In this study, water single phase turbulent flow is measured with the pipe made from the acrylic resin of 53.5mm in inside diameter. We prepare the water tank kept about 20 degree Celsius and generate micro bubbles in the tank. The average bubble diameter is 30μm. The micro bubbles produced in the water tank flow to the vertical pipe by a Mohno pump with water. The pipe length L, from the elbow to the measuring section is 3.1m, and it is equivalent to 57 times pipe diameter, D. The UVP we used is type X-3-PSi (1999).

We attached the transducer at the pipe exit with an accurate movable device. The frequency of the transducer is 4MHz, the beam diameter 5mm, and measuring range 5~100mm from the transducer tip. The time resolution of the UVP in this measurement

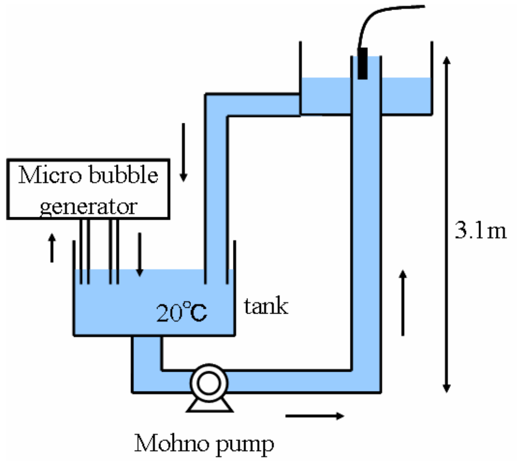

Figure 1: Experiment apparatus

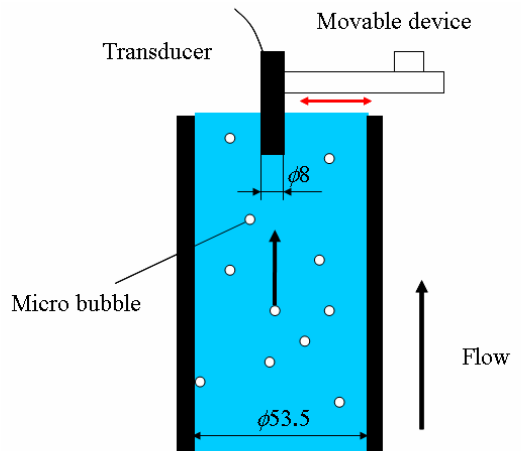

Figure 2: Setting of transducer

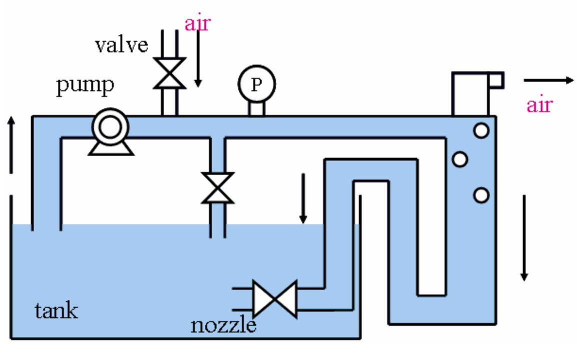

Figure 3: Micro bubble generator

is about 18~23msec, the velocity resolution 0.90~1.73mm/s, and the space resolution 0.74mm in the beam direction. This velocity resolution is 2.92 times smaller than the case setting transducer outside of the pipe at 20 degrees to the horizon.

Figure 3 illustrates a schematic of the micro bubble generator. The pressurizing dissolution system to produce micro bubbles consists of a pump (Swirl chamber pump, 20KED04S, 560W, Nikuni Co., Ltd.), a water tank (tank in Fig.1), a pressurizing pipe with an air vent, and some pipe arrangements. The back pressure valve is adjusted to create an adequate pressure in the pressurizing pipe beforehand. The pump suctions water from the water tank. This pump also aspirates air through the air valve simultaneously, and mixes water and air in its swirl chamber. The air-water mixture is then pressurized up to 0.2MPa (gauge) and sent to the pressurizing pipe.

According to the Henry's law, more air is dissolved in water in this pressurized condition than under atmospheric pressure. Extra gas, which is not dissolved in the water still exist as bubbles, is exhausted to the atmosphere through air vent. Then the flow is apparently water single phase flow. After the pressurizing pipe, the flow proceeds to the main tank of the experimental apparatus.

2.2 Data procession

To remove the noise in the obtained velocity profiles, we carried out the calculation of root-mean-square (RMS) value of the velocity fluctuation *u*' and time-averaging of the velocity data after excluding zero or negative velocity data.

Figure 4 shows the relation between the time-averaged velocities and the distance from the transducer tip under the condition of flow rate *Q*=8.89*l*/min, cross-sectional averaged flow velocity *U*=65.9 mm/s, and Reynolds number, Re=3500. The symbols exhibit the difference of the radial direction distance *r* from the pipe wall. The velocity near the transducer was affected by the existence of the transducer. It shows almost constant values within the range of 40~60mm. So that, we cut out the data from the transducer tip (0mm) to about 40mm. The data beyond about 60mm from the tip were also cut out because of the unreasonable decrease of time-averaged velocities probably because of the spreading of the ultrasonic beam. Therefore, data from about 40 to 60mm is used.

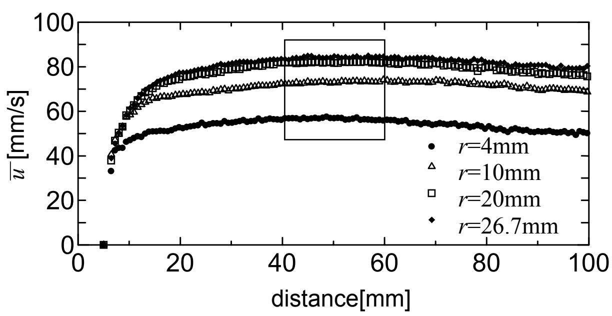

Figure 4: Plot of $\bar{u}$ vs. distance from the transducer tip

Because the space resolution in this measurement is 0.74mm, there are 29 data points in this range. When we obtain the time-averaged velocity profile, the velocity values at each data point are arithmetical averaged. Therefore, the obtained velocity profiles are both time- and space-averaged ones. Similarly, the RMS value of the velocity fluctuation $\sqrt{\overline{u'^2}}$ is first obtained locally and averaged in this range.

2.3 Adjustment of velocity profiles

As the ratio of the beam diameter (ϕ5) to the pipe diameter (ϕ53.5) is relatively large, the measured velocity by the UVP may be deviate from the local velocity at the transducer's center, especially near the pipe wall. This is because the beam-area averaged velocity differs from the transducer's center velocity. Its modification coefficient is not easily estimated analytically. Therefore, we used the Monte Carlo method to adjust this influence.

More than 50000 random numbers are generated in the range of the ultrasonic beam. The velocities at the random numbers' positions are calculated using the (1/*n*) power's law, and averaged. This average is compared with the velocity at the transducer's center is calculated using the (1/*n*) power's law, and the modification coefficient is obtained.

Considering the effect of the flotation of micro bubbles, the measured velocity includes the floating velocity of bubbles. Therefore, in order to obtain an actual velocity, 0.5mm/s is subtracted from the measured velocity data since their average diameter is about 30μm, and the mean floating velocity is 0.5mm/s.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Time-averaged velocity profiles

The time-averaged velocity profiles measured by the UVP contact measurement are shown in Fig.5. The velocity profiles almost agree well with the curve lines drawn using the (1/*n*) power's law, where the value of *n* was calculated using Eq.(1)[1].

$$n = \log_{10}(\mathrm{Re})+2 \qquad (1)$$

The mean value of the deviation from the measured and the calculated values using the (1/*n*) power's law is 2.84, 2.12, 1.98 and 0.799% respectively for Re=3500, 4200, 5200 and 7700, and their average is 1.94%.

On the other hand, the corresponding measured data by the UVP through the pipe wall with setting transducer outside of the pipe at 20 degrees to the horizon is shown in Fig.6. Although the number of data point for each velocity profile is larger than Fig.5, the deviations seem larger. The mean value of the deviation from the measured and the calculated values using the (1/*n*) power's law is 5.52, 5.69, 3.51, 2.56 and 1.67% respectively for Re=3500, 4200, 5000, 6000 and 9000, and their average is 3.79%. From these values, it is obvious that the UVP contact measurement is more effective than the UVP measurement through the pipe wall based on the perspective of the precision of the time-averaged velocity measurement.

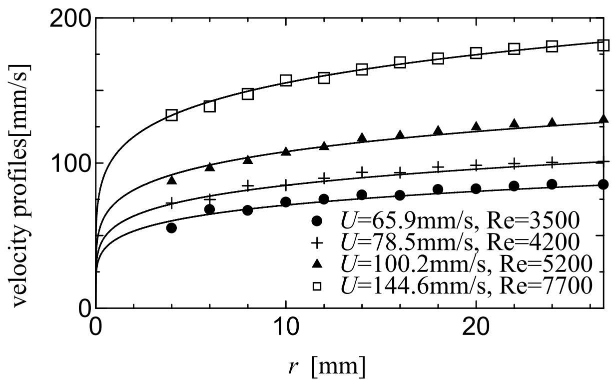

Figure 5: Time-averaged velocity profiles by the UVP contact measurement (*D*=53.5mm)

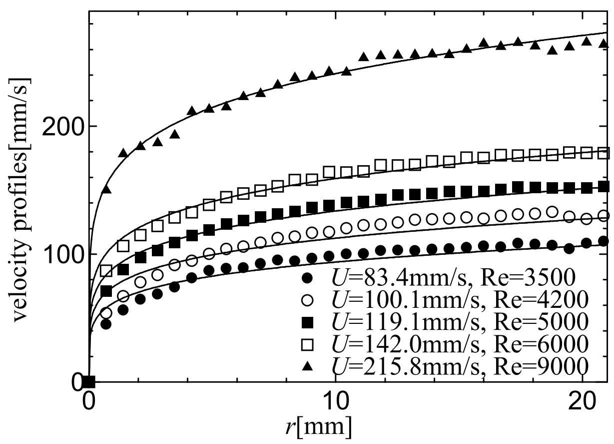

Figure 6: Time-averaged velocity profiles by the UVP through the pipe wall (*D*=42mm)

3.2 RMS value of velocity fluctuation

According to the experimental results of Hosokawa and Tomiyama [2], the turbulent length scale is about 0.2*D* except for the neighborhood of the pipe wall (*r/R*<0.2) regardless of Re in the pipe flow. Hence, the turbulent length scale is estimated about 10.7mm in this study. Under the assumption that the scale propagates at the time-averaged velocity, the frequency can be estimated at most from 7.9Hz (Re=3500) to 16.8Hz (Re=7700). The time resolution of the UVP contact measurement in this study is about 18~23msec, which correspond to 56 to 43Hz. Thus, the time resolution is satisfied in these conditions, and we try to measure the velocity fluctuation relating to the turbulent intensity. The measured results of RMS value of velocity fluctuation $\sqrt{\overline{u'^2}}$ divided by the cross-sectional averaged flow velocity *U* are presented in Fig.7 with Hosokawa et al.[2]'s data measured by a LDV and Laufer[3]'s data measured by a heat-wire airflow meter. According to Fig.7, the values of $\sqrt{\overline{u'^2}}/U$ are larger near the pipe wall. It decreases to the pipe center. This tendency agrees with the existing data [2-3]. The smaller Re is, the larger the values of $\sqrt{\overline{u'^2}}/U$ especially near the pipe wall similarly to the existing data. These tendencies prove the data obtained by the UVP contact measurement in this study are validated.

On the other hand, Figure 8 shows the corresponding data measured by the UVP through the pipe wall. The tendencies of the data presented in Fig.7 are not recognized. The values are much larger. Therefore, these RMS values measured by the UVP through the pipe wall in this study are confirmed to be useless. This is probably because of the insufficient velocity resolution and the shortage of signal to noise ratio.

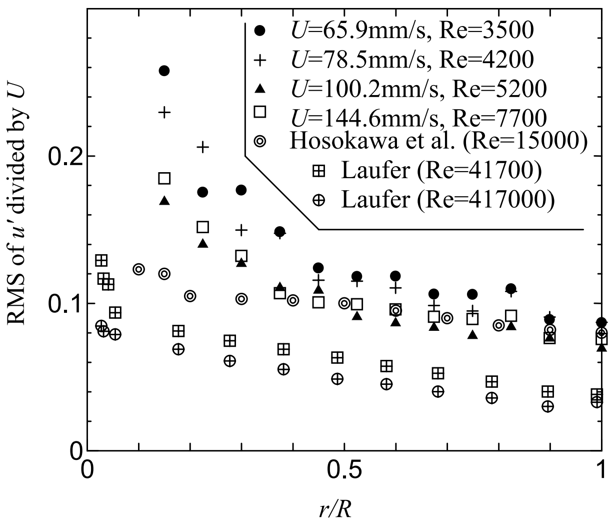

Figure 7: RMS value of velocity fluctuation $\sqrt{\overline{u'^2}}$ divided by the cross-sectional averaged flow velocity *U* measured by the UVP contact measurement (*D*=53.5mm) together with existing data

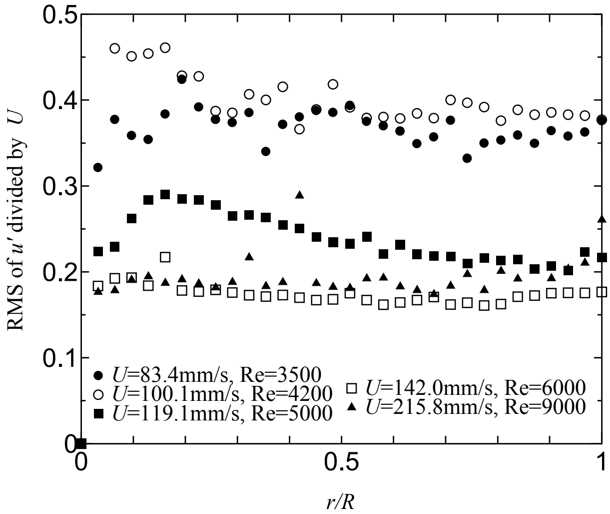

Figure 8: RMS value of velocity fluctuation $\sqrt{\overline{u'^2}}$ divided by the cross-sectional averaged flow velocity *U* measured by the UVP through the pipe wall (*D*=42mm)

4 CONCLUSIONS

In this study, we directly inserted the transducer of the UVP with an accurate movable device into the flow parallel to the flow axis. In order to verify the validity of this method, we measured the velocity distribution and computed the root-mean-square value of the velocity fluctuation in turbulent flow of the water single phase in a vertical pipe of 53.5mm I.D.

As the results of the measurement, the conclusions are obtained as follows:

1. The time-averaged velocity profiles measured by the UVP contact measurement agreed well with the calculated results by the (1/*n*) power's law. The deviations are smaller than those measured by the UVP measurement through the pipe wall.

2. RMS values of velocity fluctuation $\sqrt{\overline{u'^2}}$ divided by the cross-sectional averaged flow velocity *U* are presented by the UVP contact measurement. The results agreed with the tendencies of Hosokawa et al.'s and Laufer's data. In this case, the measured results by the UVP measurement through the pipe wall were also insufficient.

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